QUANTIFICATION OF ENERGY AND ENVIRONMENTAL ASPECTS OF IRANIAN DAIRY FARMS BASED ON OPTIMAL NUTRITION

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Abstract – Input and output energy are all important aspects for evaluating the performance of dairy farms which have been used in a multi-indicator modeling approach to optimize the performance of30 dairy farms in Khorasan Razavi Province (Iran). Total input and output energy, energy ratio, energy productivity, and net energy gain across all farms are 7.5×10^{08} MJ, 4×10^{08} MJ, 0.53, 0.13 kg/MJ and -3.5×10^{08} MJ, respectively. Therefore, in order to reduce the energy "consumption" for dairy farms in this region, we built an optimization model using multi-objective fractional mathematical programming and considered the renewable energy, energy intensity, GHG emissions, and animal feed costs as objective functions. Total optimization achieved all goals is 0.5467. The proposed nutrition was confirmed based on the results of the main model and means if the farmers use the proposed diet including 26.8 kg/day, 22.2 kg/day and 19 kg/day of total intake feed for high milk cow, middle milk cow and low milk cow, respectively, in addition to reducing feed costs, energy consumption and GHG emissions associated with dairy farms will also decrease. Our model can be used in various contexts to improve the environmental and energy performance of dairy farms based on an optimal nutrition.

Keywords - Energy indicators, Dairy cattle nutrition, Multi-objective fractional mathematical programming, Dairy farms, Iran.

I. INTRODUCTION

The advancement of technology and the improvement of productivity in dairy farms has been one of the mostimportant factors in economic growth and development in Iranover the last few decades.In the coming years, energy costs will increase dramatically in agricultural and industrial production processes(Qobadi. M, 2015).In the field of global competition in production, countries, and industries will be more successful in finding ways to prevent waste of energy.The milk production industry is one of themost important and energy-intensive agricultural sectors,especially in Iran(Rafiee et al., 2016).A dairy farm unit is both an energy "consumer" and anenergy "producer"(Wells, 2001).Total primary energy input implies that all forms of energy, measured at the source, for example, direct energy (fuel, machinery, nutrition, labor, and electricity) and indirect energy(for theproduction of consumables such as fertilizer, etc.)(Wells, 2001)that increasing consumption of these resources will increase the cost of production and associated environmental pollution (Qobadi. M, 2015).Many1. aspects of energy consumption in the production of milk areunclear, and the main reasonsare thatit is often not clear for the farmer how to use energy in an optimal way.Nutrition has a significant impact on livestock production and health, in addition to, it has the highest levels of energy consumption compared to other aspects of dairy farms(Sefeedpari, 2012). Therefore, optimizing energy consumption in dairy farms is important.Most studies have, however,only considered the technical production efficiency of dairy farms.Barnes (Barnes, 2006), Kirner(Kirner et al., 2007), Uzmay(Uzmay et al., 2009), Dagistan(Dagistan et al., 2009),Qobadi and Shahrami(Qobadi. M, 2015)and Sefeedpari et al(Sefeedpari, 2012)studied on energy consumption in Dairy Farm based on DEA[1].

Based on the existing published literature, studiesfocusing on the overalloptimization of energy consumption in industrial dairy farms have not been carried out in Iran. Therefore, it is the aim of the present study to determinethe energy and environmental performance of dairy farms in Iran based onenergy consumption, greenhouse gas (GHG)direct emissions, renewable energy, energy intensity, and feed costsusing optimization of dairy cattle nutrition, and identify uses where energy is wasted from different inputs for milk production in Khorasan-e-Razavi province of Iran.Overall, the purpose of this research is to study the energy status of consuming inputs and optimize them based on dairy farm nutrition. Our study should helpthe farmers to modify the dairy cattle diet program in order to reduce energy consumption and feed costs.

Material and Methods

Data used in ourstudy were gathered from 30 dairy farms through questionnaires and interviews during 2016. Dairy farms were evaluated in terms of data for energy consumption, GHG emissions, and nutrition standards.The input and output energy of each farm are calculated by considering their energy content (according to the used sources which are givenin Table 1) and related relationships between farm

[1]Data Envelopment Analysis

inputs.We then converted all inputs into energy equivalent which are obtained from the formulas given in Table 2.

Table 1.Energy content of inputs and outputs in dairy farms

Input Energy	Unit	Energy Content (MJ/unit)	References
Input			
Labor	H	1.96	(Krebs, 2002)
Machinery			
a-Weight of tractor	Kg	9-10	(Gezer et al., 2003)
b-Fix equipment	Kg	8-10	(Gezer et al., 2003)
c-Electronic motor	Kg	64.8	(Gezer et al., 2003)
Fuel			
a-Diesel	L	47.8	(Gezer et al., 2003)
b-Gas	m^3	49.5	(Gezer et al., 2003)
c-Gasoline	L	46.3	(Gezer et al., 2003)
Electricity	kWh	11.93	(Engineering and Kitani, 1999)
Feed			
a-Concentrate	Kg	6.3	(Komleh et al., 2011)
b-Silage	Kg	2.2	(Ozkan et al., 2004)
c-Alfalfa	Kg	1.5	(Meul et al., 2007)
d-Straw	Kg	12.5	(Qobadi. M, 2015)
Output			
Milk	kg	3.5	(Qobadi. M, 2015)
Calf	kg	6.5	(Frorip et al., 2012)
Meat	kg	9.22	(Frorip et al., 2012)
Cow Manure	m^3	303.1	(Mobtaker et al., 2010)

Table 2.Formulas for calculating equivalent energy inputs and outputs of dairy farms

Equivalent Energy	Formula	Description
Equivalent Energy of fuel consumption	$E_f = F_c \times E_{c,f}$	E_f: Equivalent energy of fuel consumption (MJ). F_c: Amount of fuel consumed (L). $E_{c,f}$: Unit fuel energy content (MJ/L)
Equivalent Energy of electricity consumption	$E_{elec} = E_{el} \times E_{c,el}$	E_{elec}: Equivalent energy of electricity consumption (MJ). E_{el}: Amount of electricity consumed (kWh). $E_{c,el}$: Unit electricity energy content (MJ/kWh)
Equivalent Energy of labor consumption	$E_{la} = N_{la} \times h \times E_{c,la}$	E_{la}: Equivalent energy of laborwork (MJ). N_{la}: Number of labor workers. h: Hours work (h). $E_{c,la}$: Unit labor energy content (MJ/per person)
Equivalent Energy of machinery consumption	$E_m = W_m \times E_{c,m}$	E_m: Equivalent energy of machine (MJ). W_m: Mass of machine (kg). $E_{c,m}$: Unit machine energy content (MJ/kg)
Equivalent Energy of feed consumption	$E_N = W_N \times E_{c,N}$	E_N: Equivalent energy of feed consumption (MJ). W_N: Feed consumed (kg). $E_{c,N}$: Unit feed energy content (MJ/kg)
Equivalent Energy of farm outputs	$E_{ou} = W_{ou} \times E_{c,kg}$	E_{ou}: Equivalent energy of output production including: Milk, Calf, Meat & Cow manure (MJ). W_{ou}: Output production (kg). $E_{c,kg}$: Unit output energy content

Three important energy indicators are used to recognize the state of energy in agriculture, the various approaches of production and the possibility of comparing energy efficiency in a production system as information for researchers, managers, and policy-makers, which include: energy ratio, energy productivity, and net energy gain.The energy ratio is one of the important indicators in the energy assessment, which is the total amount of energy output (‘production energy’) to the total input energy (‘consumed energy’). This indicatoris dimensionlessand is defined as the impact of energy input per MJ of energy obtained at the output(Engineering and Kitani, 1999).Net energy gain (NEG),also known as net energy production is defined as the difference between the total energy equivalent output and the total energy equivalent inputs.Indeed, it shows whether the energy is stored in the production process or not(Engineering and Kitani, 1999).Energy productivity (EP) is indicativefor the amount of production in the energy input unit and shows the amount of milk that is produced per MJ of energy. In order to improve energy efficiency in a dairy farm process, a farmer can reduce energy consumption in inputs or improve product performance or cure losses(Engineering and Kitani, 1999). The calculation of these indicators is based on equations (1) to (3).

$$ER = \frac{E_{out}}{E_{in}}$$

$$NEG = E_{out} - E_{in}$$

$$EP = \frac{Y}{E_{in}}$$

where ER: energy ratio (%), E_{out} and E_{in}:outputand input energy equivalent (MJ),NEG: net energy gain (MJ), EP: energy productivity (MJ), and Y: Yield of milk production (L).

A multi-objective programming or vector optimization technique is used to simultaneously optimize multiple targets, provided that a certain set of constraints is present (Sabuhi. M., 2006).In this study, because each goal hasa different relative importance, we used the weighting method and weights are assigned to each ofthe goals via the analytichierarchy process (AHP) using Expert Choice Software. AHP is based on the concept of the pairwise comparison ofthe goals to arrive at a weight for each element of the objective function of the evaluation of experts(Saaty, 2008). Theinconsistency ratio is calculated by theratio, CI/RI, where CI is the consistency index and RI is the random index, and where the pairwise comparison is considered consistent if the ratioCI/RI is less than 0.1(Saaty, 2008). Hence, amulti-objective mathematical programming model was developed based on the main objectives of the research, which is to optimize energy use, reducing GHG emissions based on a standard nutrition in a dairy farms. The objective function therefore includes renewable energy, energy intensity, GHG direct emissions, and feed costs. Renewable energy (equation 4) on dairy farms includes feed and labor equivalent energy(Sefeedpari, 2012).Energyintensitymeansthe energy consumption for the production of specific goods in each country, and the total input energy is divided by a number of goods produced in its value(equation 5). GHG direct emissions are considered in this study, direct emissions in dairy farms originate from CO_2, CH_4, N_2O emissions resulting from the process of milk producing (equation 6)(Sefeedpari, 2012).CO_2calculated based on emission CO_2-equivalents (kg CO_2-eq) through fuel and electricity consumption in dairy farms. $CH_4$is released in two ways in dairy farms: rumen based on rumination, and manure. By including the amount of feed consumed in $CNCP_{SV}$65 software, the amount of CH_4 released from the rumen was obtained. $CH_4$from manure is 3% of the methane emitted from the rumen.The effect of CH_4emissions is 25 times that of CO_2 emissions. Based on this, the total methane production was converted to CO_2 equivalents emitted.The N_2Oemission on average is calculated for each dairy cow, 1.1378 kg/year.The effect of N_2Oemissions is 300 times that of CO_2emissions, hence the total N_2O production was converted to CO_2 equivalents emitted, too.One of the major cost items in dairy farms is the feeds costs, which can be reduced by adapting the diet and considering available inputs.

$$er = \frac{E_N + E_{la}}{E_{ou}}$$

$$int = 1 - \left(\frac{E_{ou}}{\sum_{p=1}^{2} m_p V_p}\right)$$

$$GHG = 1 - \left(\frac{CO_2 + CH_4 + N_2O}{K}\right)$$

Where is er: renewable energy, int: energy intensity, K: amount of cattle farm inputs, p: production (milk, calf), V_p: value of p (IRR). Overall, our final model is given in equation (7):

$$\text{Max obj. f: } W_{er}er + W_{int}int + W_{GHG}GHG + W_C C_{X_j}$$

$$\text{S. to:}$$

$$\text{a) } \sum C_j X_j \geq Z^* \qquad (7)$$

$$\text{b) } 0 \leq \{er, int, GHG\} \leq 1$$

$$\text{c) } X_j \geq N^*$$

$$\text{d) } X_j \geq 0$$

Where C_j is feed costs (IRR), X_j is feed and decision variable, and $Z^*$are the optimal costs(IRR) derived from linear mathematical programming,N^* is purposed nutrition,Wis a weight of each goals in objective function. The constraint (a) ensures that the cost of proposed feed does not exceed the optimum value.The goals in the objective function are normalized because they do not have the same unit and accordingly, constraint (b), indicates per target will be between zero and one.Constraint (c) is related to feed, which means that the feed should not more than the daily requirements of the cattle and constraint (d)expresses non-negative decision variables.

RESULTS AND DISCUSSION

First, based on the data and information through questionnaires completed and interviews performed, the energy indicators were calculated as shown in Table 3.The results show that total energy consumption for all dairy farmsis on average7.5×10^{08}

MJ.According to Table 3, livestock feeds with 4.93×10^{08} MJ contributes with 66% to the total energy consumption,whilelabor with 6146.56 MJ has with onlyless than 1%the lowest contribution to overall energy consumption in dairy farms under study. Fuel was the second most energy-consuming input with 25% and 1.9×10^{08} MJ in the present study.Fossil fuels such as diesel fuel are used to process animal feed in the farms. Electricity with 6.6×10^{07} MJ and 9% of total energy consumption is the third most energy-consuming input, which is the most used in milking systems, water heaters, and milk coolers.We included for each farm all machines, including tractors, milking, feeding machines that are considered the minimum necessary equipment.The total output energy is estimated to be3.96×10^{08} MJ and Milk production with 3.39×10^{08} MJ has the highest share (86%).

The purpose of calculating energy indices is the possibility of studying and comparing production systems in different regions or products.The average energy ratio in this study was 53% across dairy farms. This ratio shows that on average 53% of energy is produced for eachMJ of input energy.To improve this ratio, the production function can be increased or energy inputs can be decreasedor both.0.13kg/MJ energy productivity is achieved on average and means that for each MJ, around 0.13 kg/MJ of milk is produced, and according to NEG's conclusion, energy is not stored in the production process. In other words, the dairy farms studied are effectively losing energy.

Table 3.Results of Equivalent Energy Indicators of Dairy Farms

Input and output	Equivalent energy (MJ)	Percent (%)	Energy Ratio	Energy Productivity	Net Energy Gain
Input					
Fuel	1.9×10^{08}	25.37			
Electricity	6.6×10^{07}	8.8			
Feed	4.9×10^{08}	65.69			
Machinery	1×10^{06}	0.14			
Labor	6146.56	0.0008			
Sum	7.5×10^{08}	100	0.528	0.129 (kg/MJ)	-3.54×10^{08} (MJ)
Output					
Milk	3.39×10^{08}	85.68			
Calf was born	1×10^{06}	0.27			
Meat	3.3×10^{07}	8.38			
Cow manure	2.2×10^{07}	5.67			
Sum	3.96×10^{08}	100			

Then, after calculating the energy indices and examining the current state of the studied dairy farms, a multi-objective fractional programming model was proposed and designed to optimize energy consumption, which is to be maximized.According to the results of our model, feed in addition to the high energy consumption has the largest share in the costs of dairy farms. Therefore, it is essential to develop a proper nutritional programfor dairy farms, taking into account the basic nutritional needs, minimizing costs and energy consumption.

Overall, the considered model has been solved using Microsoft Excel. Table 5 summarizes the model results. Total optimization achieved across all goals included in the objective function is 0.5467 (54.67 %). GHG, energy intensity and renewable energy consumptionare recommended to be decreased by0.4% and 0.2% and to be increased by 0.6%, respectively,in order to use an optimal energy in the production process. The results for an optimal nutrition of considered modelmatches the proposed nutrition. It means the diet considered in addition to reducing feed cost, could reduce energy consumption.

Table 4. Summary of Results

Variable		Value	Units
Alfalfa	High milk cow	4.05	Per kg/day/cow
	Middle milk cow	3.6	
	Low milk cow	3.15	
Corn silage	High milk cow	6	Per kg/day/cow
	Middle milk cow	6	
	Low milk cow	5.5	
Wheat Straw	High milk cow	0.464	Per kg/day/cow
	Middle milk cow	0	
	Low milk cow	0.464	
concentrate	High milk cow	16.5	Per kg/day/cow
	Middle milk cow	14	
	Low milk cow	11	

Renewable energy	0.6	%
Intensive energy	-0.2	%
GHG	0.43	%
Objective function	54.67	%

Previous studies such as (Sefeedpari, 2012, Qobadi. M, 2015) investigated, compared and determined the efficiency of industrial dairy cattle units, using the data envelopment analysis method. However, in some of these studies(Qobadi. M, 2015, Sefeedpari, 2012, Hosseinzadeh-Bandbafha et al., 2017, Khoshnevisan et al., 2013a, Khoshnevisan et al., 2013b, Pahlavan et al., 2012), energy indicators such as EP, ER, and NEG were estimated, but none of these studies provided a solution to reduce overall energy consumption in dairy farmsbesides DEA.In line with our results, an overall energy efficiency can be achieved only by considering per unit of inputs used, how much output is produced and then combine all aspects in an overall optimization model to arrive at a solution that can effectively be recommended to farmers.Thereby, aninput unit is efficient when its production rate is the same as its consumption.

Maximizing profits and minimizing costs are two important economic objectives per production unit.Generally, manufacturing units in Iran focus only on these two objectives,while other factors such as environmental, social and other factors, are mostly ignored.According to the results of our study, where some of the environmental factors, in addition to the economic factor of minimizing feed costs, were examined and evaluated, it is important to also include other than only economic objectives if overall optimized production should be achieved. According to the results of our interviews, dairy farmers raise production to maximize profits, which will on the other hand increase the costs of production, energy consumption, and so on and in the long run, they will face a loss of profits if they do not optimize their entire production system. Our proposed model allows the dairy farmer to consider several important environmental objectives in addition to minimizing feed costs, by optimally using energy. According to our results, including and optimizing environmental objectives reduces other dairy farm costs, and ultimately leads to higher profits (without the need to increase production).In order to improve the present model, in addition to environmental and energy factors, it is suggested that other factors affecting the process of reducing production costs are identified, evaluated and introduced in the overall optimization. For instance, the policy of producer support estimates (PSE) is one of the most important factors in this regard in Iran. Quality factors of milk production and set prices accordingly are other factors that can be additionally considered in the optimization of dairy farm production.

CONCLUSIONS

This study was accomplished in Khorasan-e-Razavi province of Iran in order to optimize some environmental indicators such as energy consumption, energy-intensity, etc. by optimization of dairy cattle nutrition using multi-objective mathematical programming in industrial dairy farms. Based on the first part of results, energy consumption is very high in the study subjects,especially related to the cattle feed intake, so that not only energy is not stored in the production process, but also energy is lost.Multi-objective mathematical programming allows to optimizing several goals simultaneously and getting a feasible solution. According to our findings, livestock nutrition needs and increased yields as well as energy consumption, direct and particularly indirect greenhouse gas emissions and finally livestock costs should be minimized in a combined approach to yield maximum optimization. In the other hand, the selectionof feed for dairy cattle is important and significant.Therefore, it is suggested, dairy cattle nutrition to be based on the standard dairy ratio patterns.In order to achieve an optimal result, a reduction in feed costs, energy wasting of feed intake, was considered and consequently, the decline of GHG emissions, increase of production performance, profitability and sustainability will happen in industrial dairy farms.

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